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Nakahara

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[54] **90 DEGREE PHASE SHIFTER**

[75] Inventor: **Kazuhiko Nakahara**, Itami, Japan

[73] Assignee: **Mitsubishi Denki Kabushiki Kaisha**, Tokyo, Japan

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[30] **Foreign Application Priority Data**

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[51] **Int. Cl.**[6] **H01P 1/18**; H03H 7/18

[52] **U.S. Cl.** **333/161**; 333/164

[58] **Field of Search** 333/103, 104, 138, 140, 333/156, 161, 164

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Primary Examiner—Seungsook Ham

Attorney, Agent, or Firm—Leydig, Voit & Mayer

[57] **ABSTRACT**

A switched line type 90° phase shifter includes two single pole double throw switches, a reference transmission line having an electrical length of α connected between output terminals of the first and the second single pole double throw switches, a phase difference producing transmission line having an electrical length of $(90°+\alpha)$ at a usage frequency, connected between other output terminals of the first and the second single pole double throw switches, and a phase inverting circuit switchablely connected for serial connection to and between two parts of the reference transmission line, which two parts produce the entirety of the reference transmission line, the one terminal of the first single pole double throw switch is an input terminal of the entire terminal and one terminal of the second single pole double throw switch is an output terminal.

5 Claims, 11 Drawing Sheets

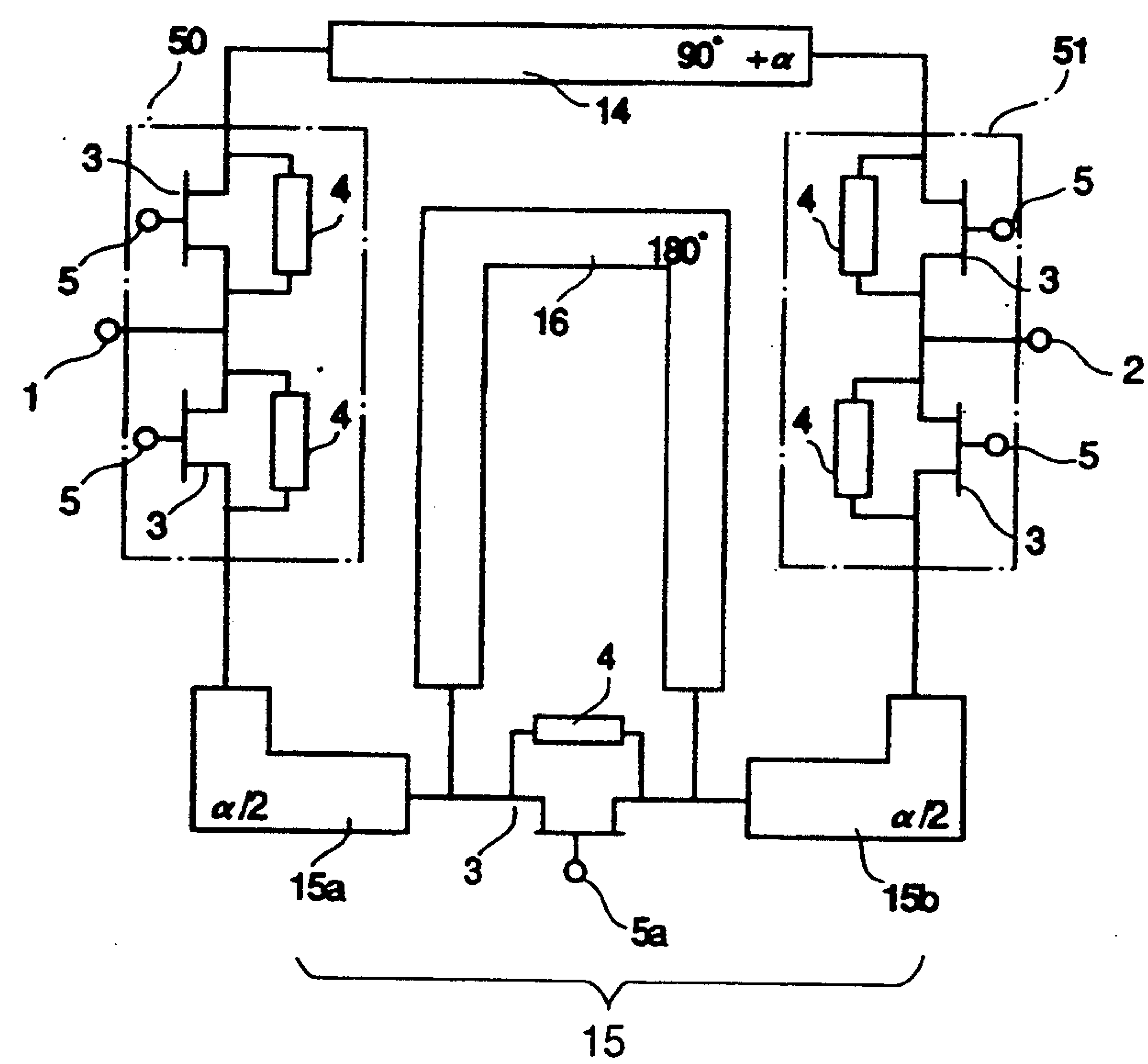


Fig.1

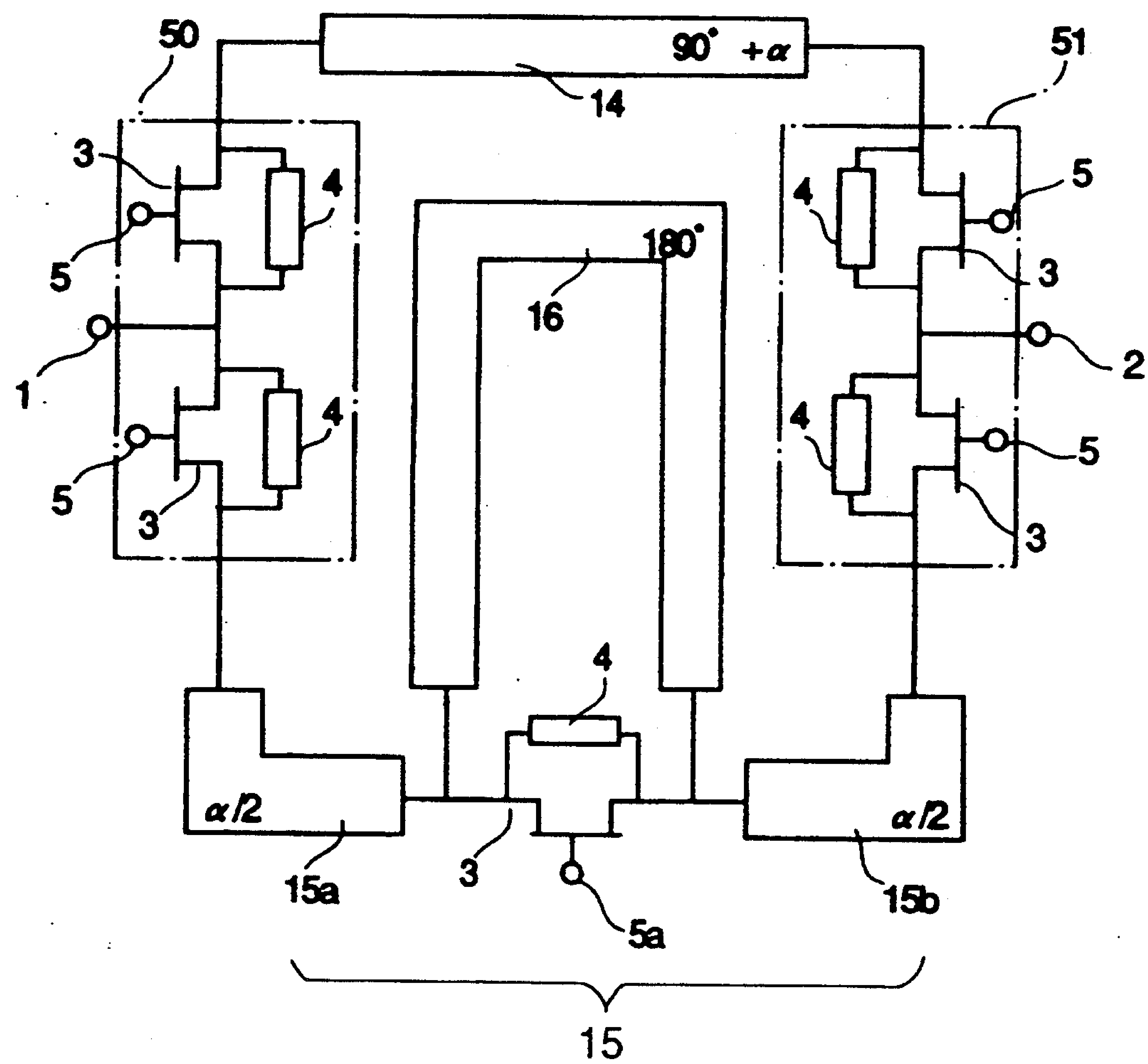


Fig.2

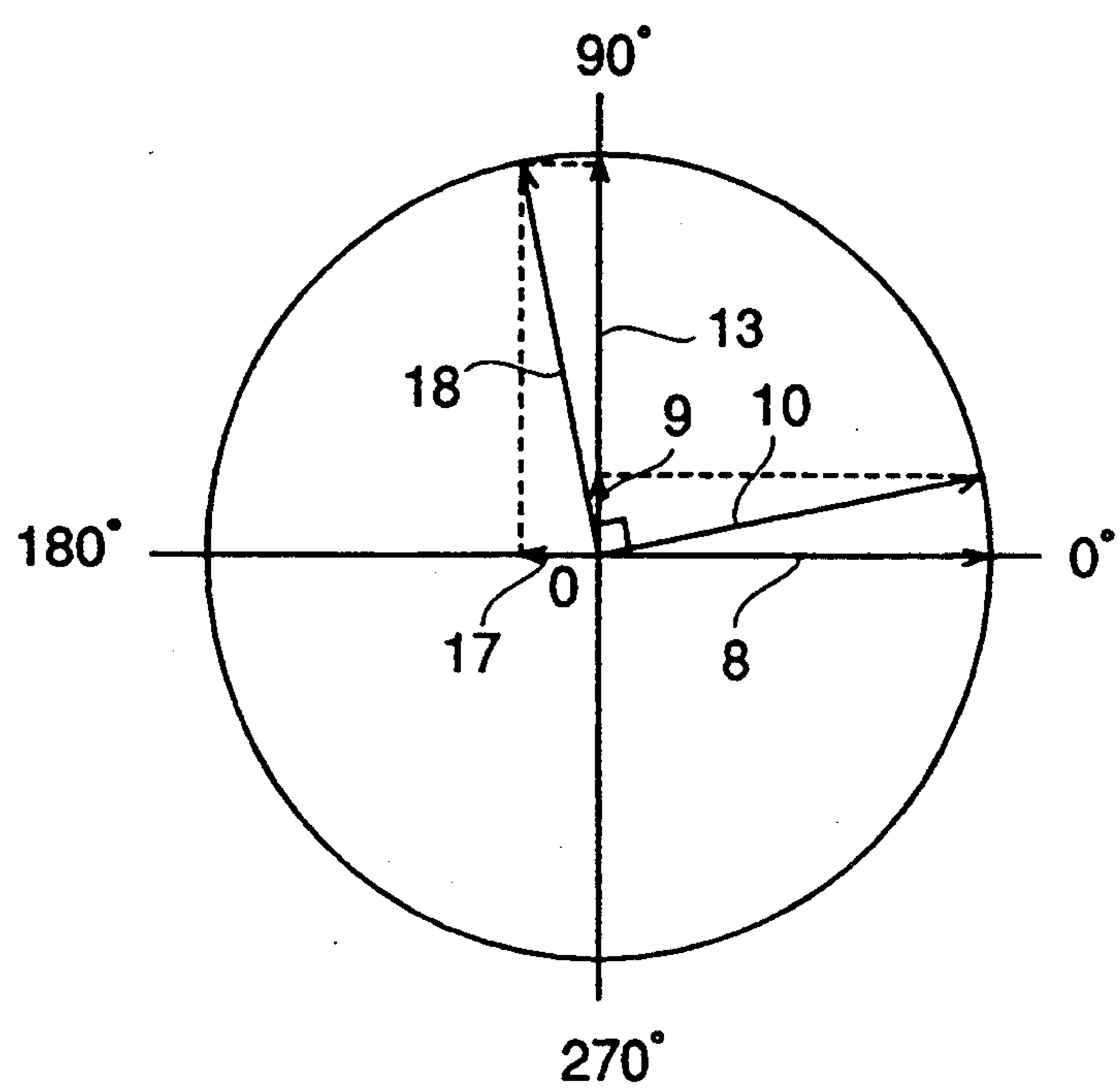


Fig.3

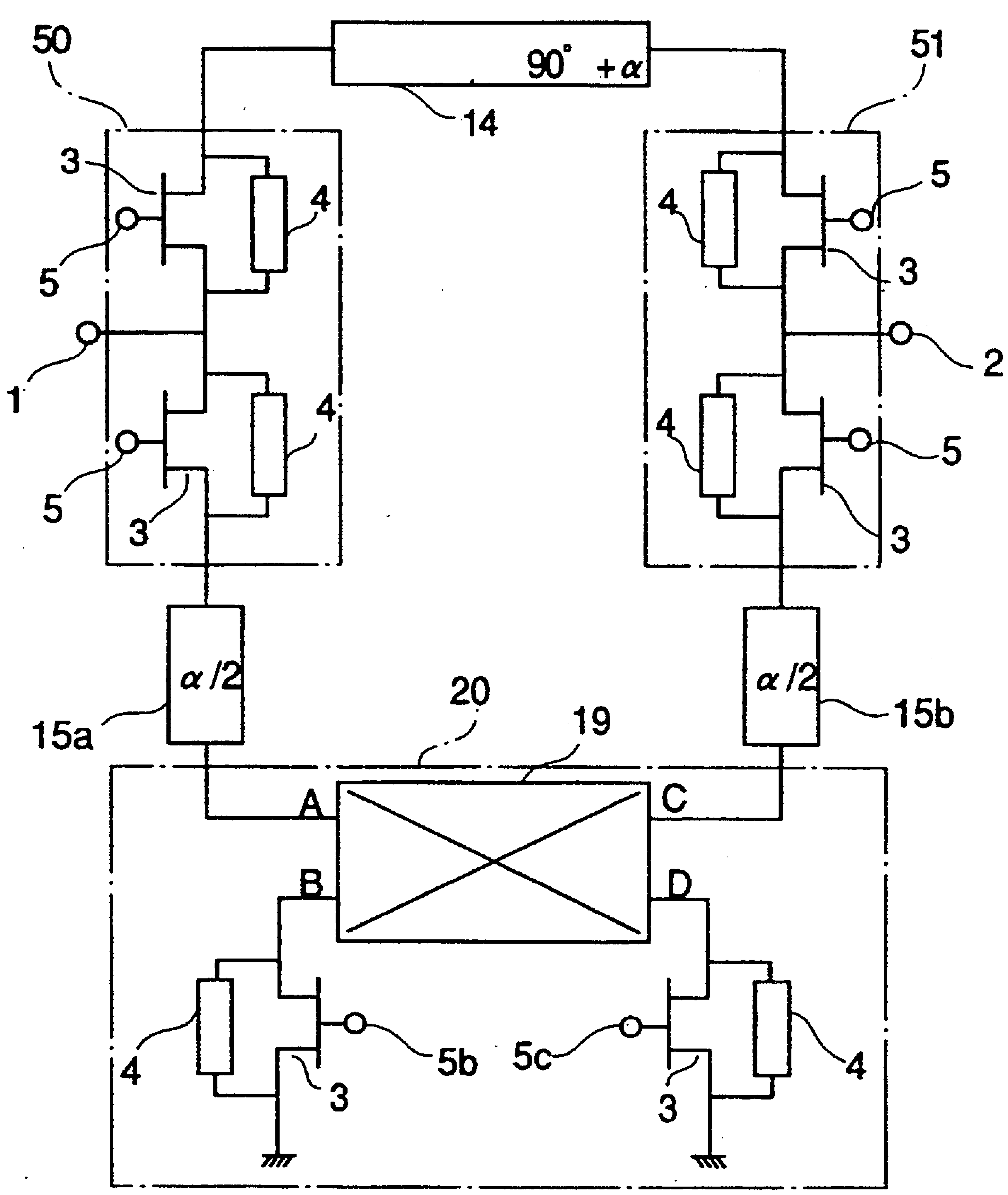


Fig.4

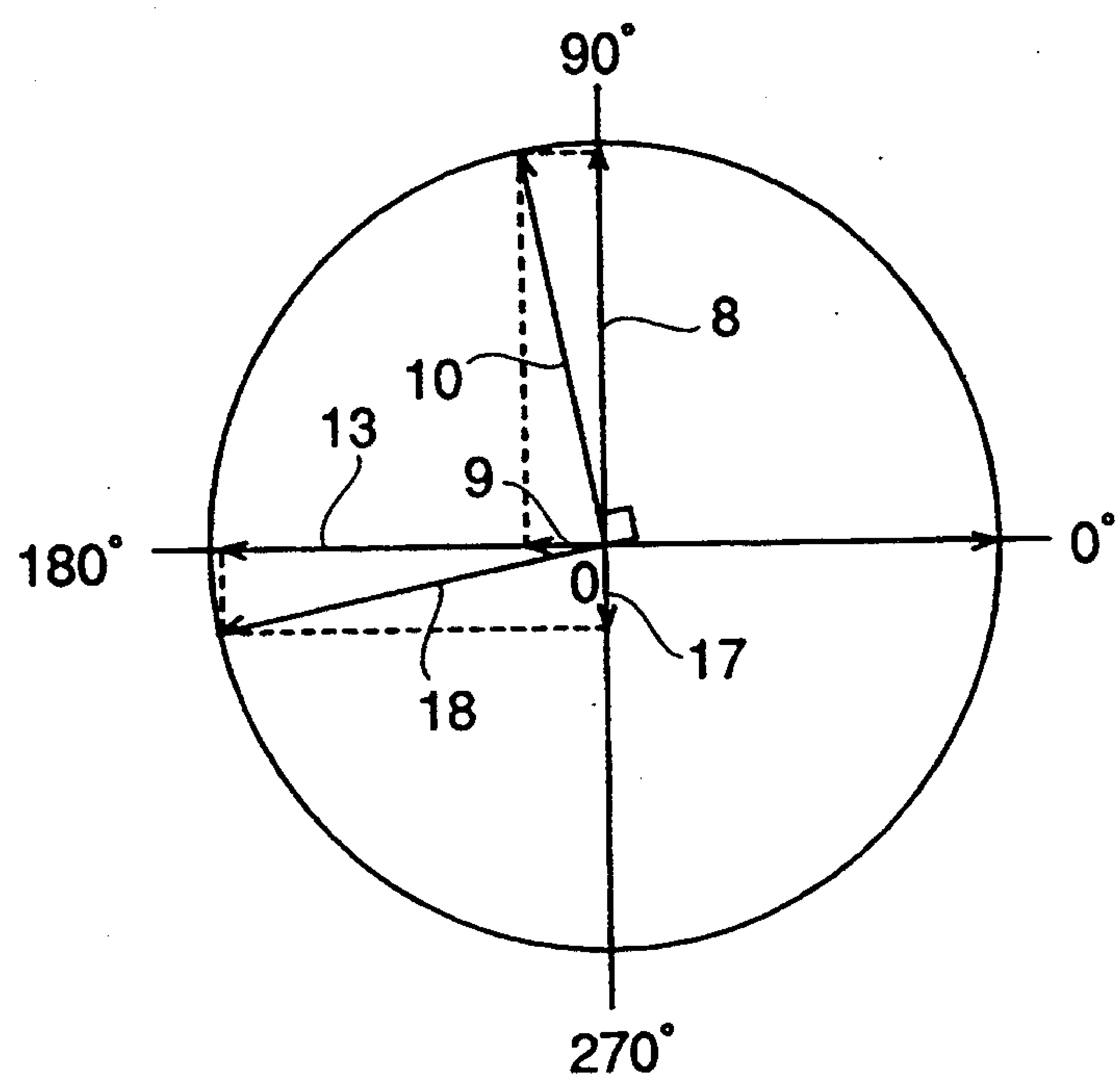


Fig.5 (a)

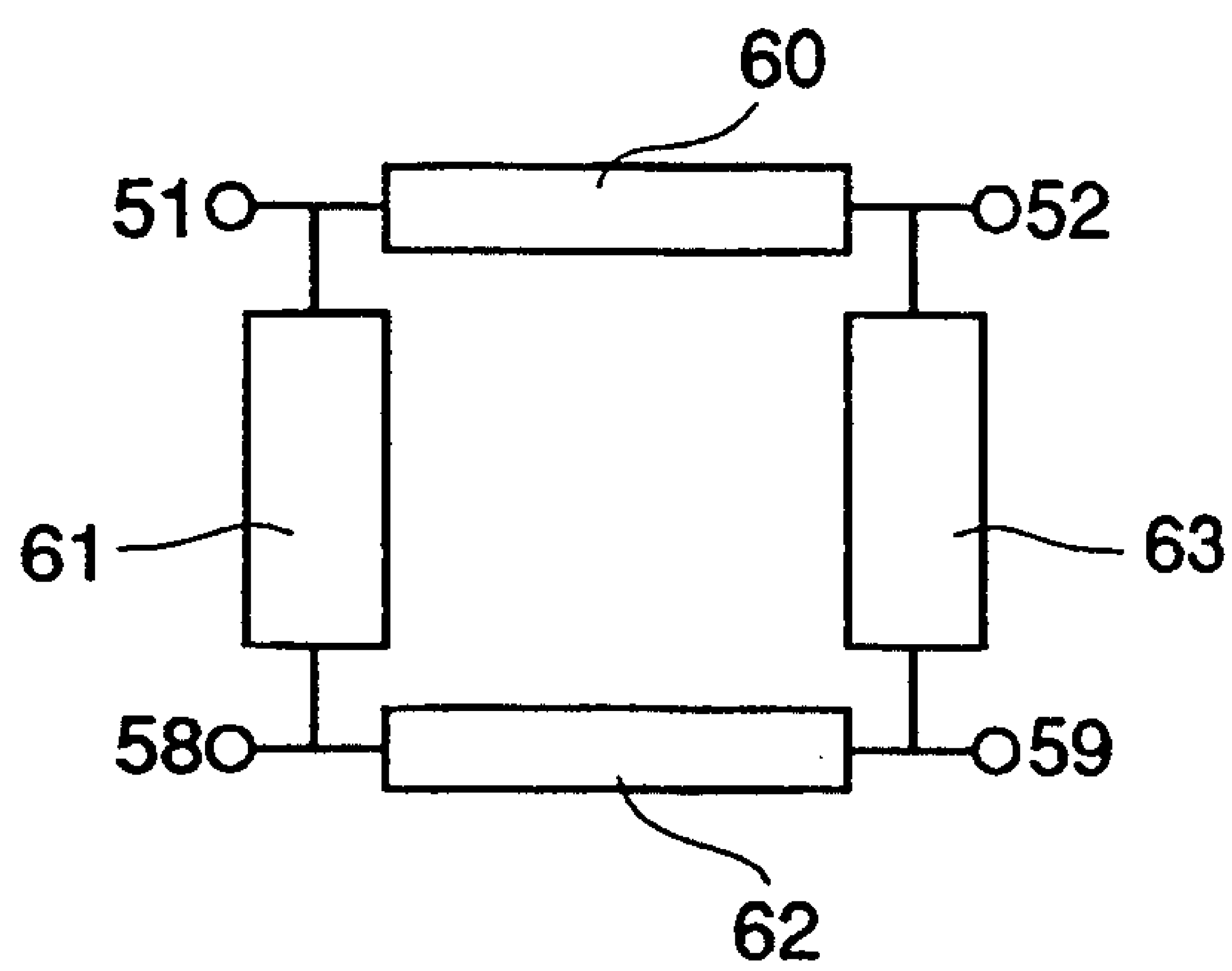


Fig.5 (b)

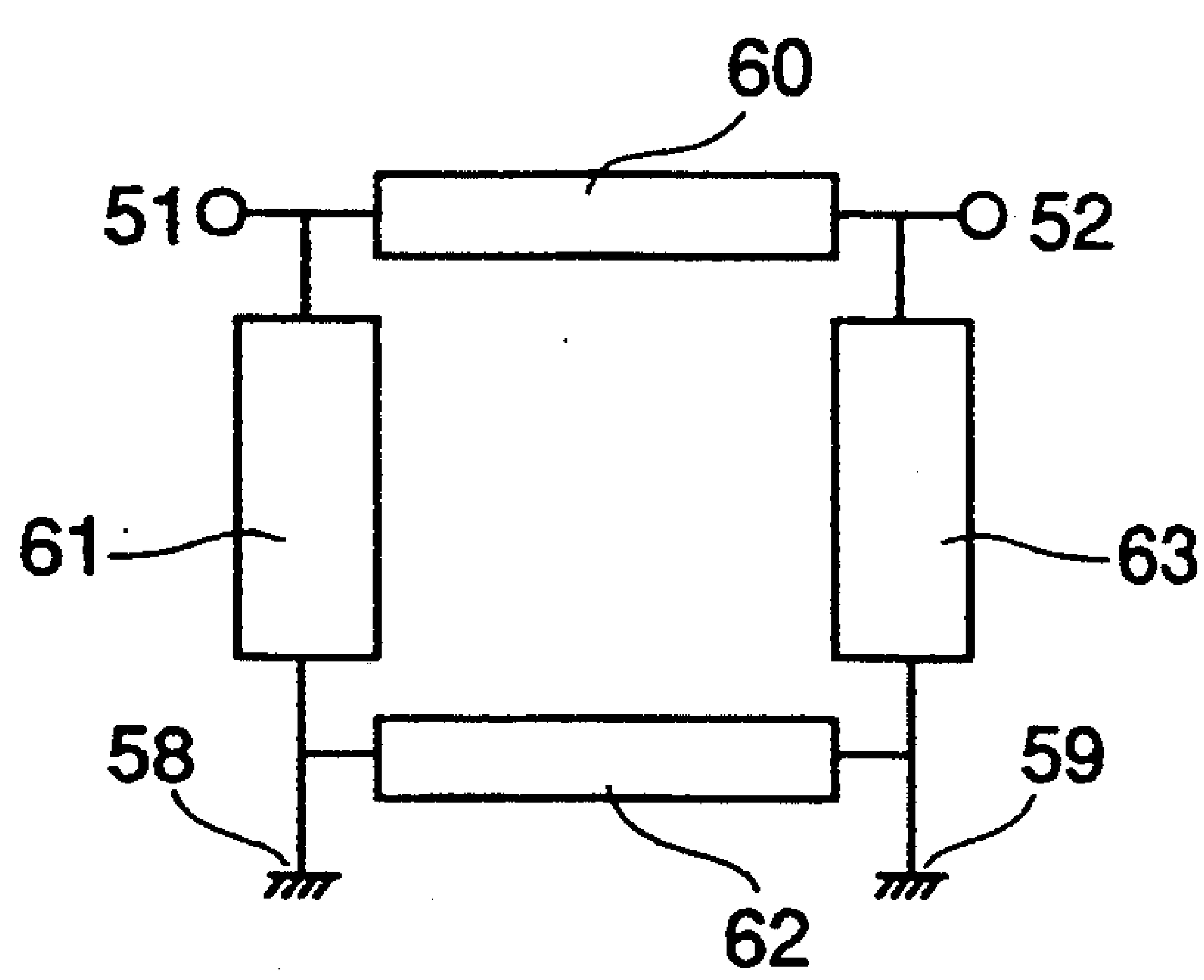


Fig.5 (c)

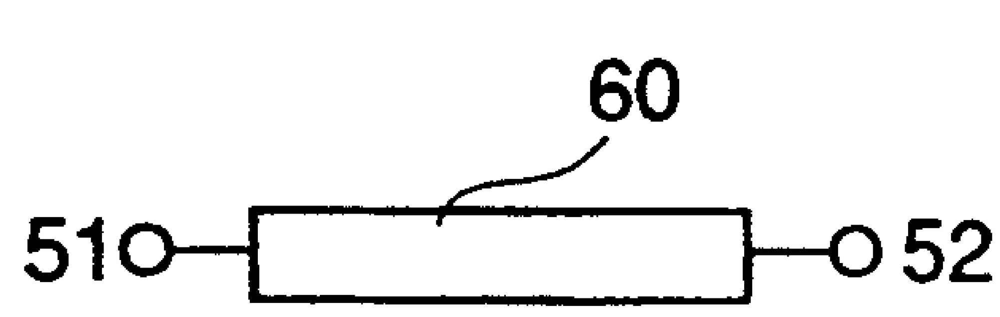


Fig.5 (d)

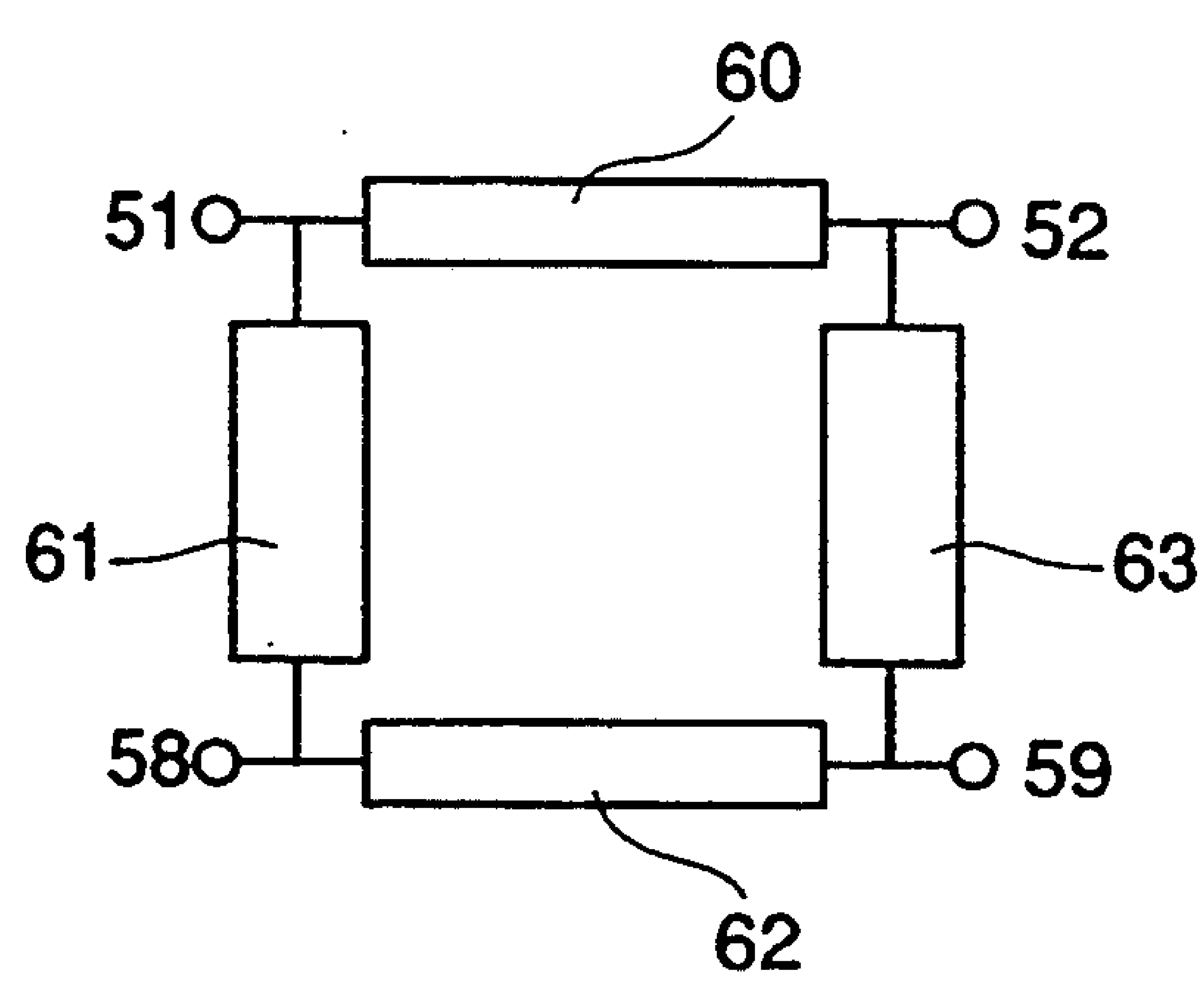


Fig.5 (e)

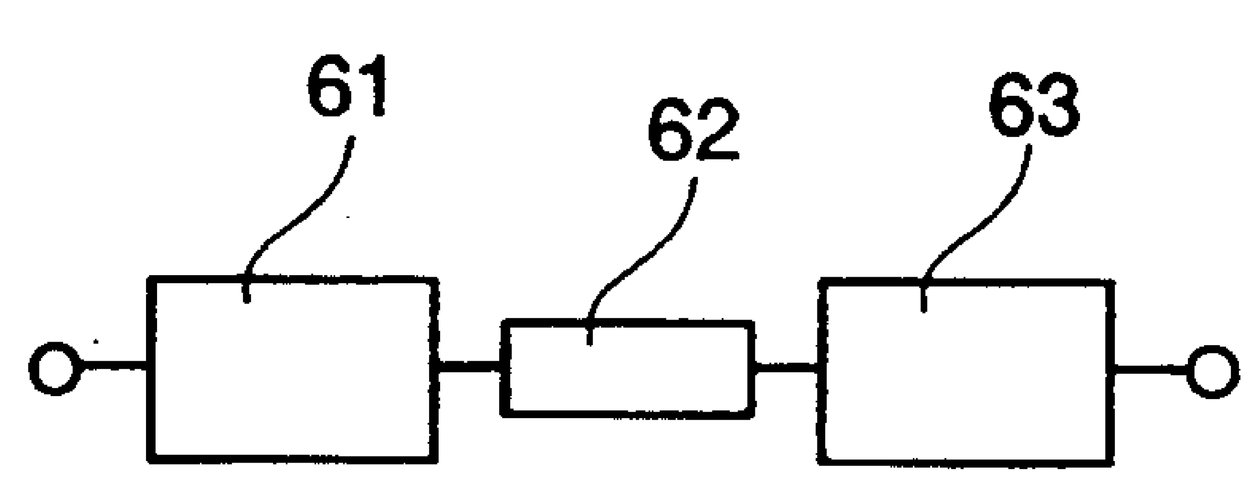
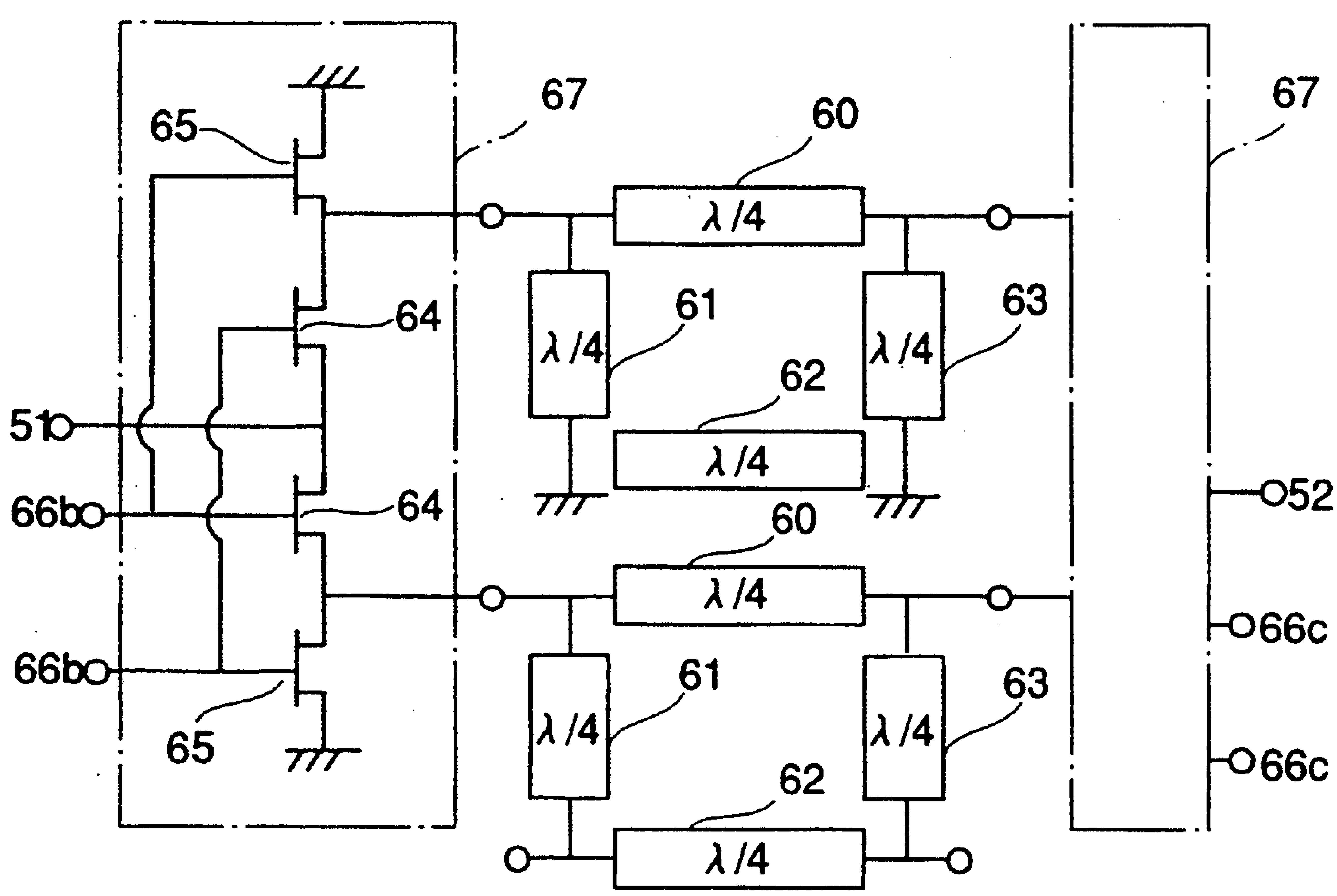


Fig.6


65
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66b
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62
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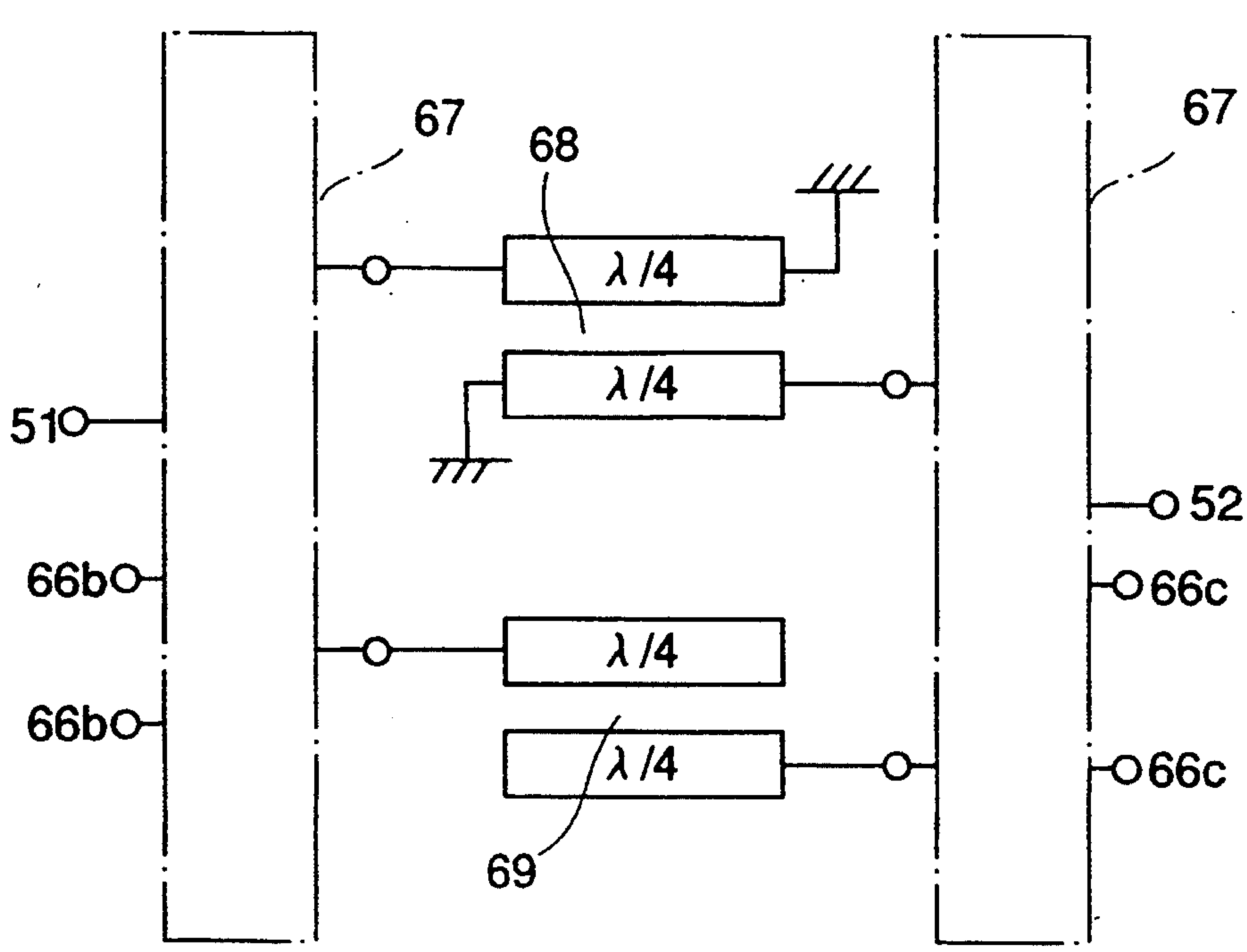
66c
66c

Fig.7


67
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52
66b
66c
66b
66c
69

Fig.8 (Prior Art)

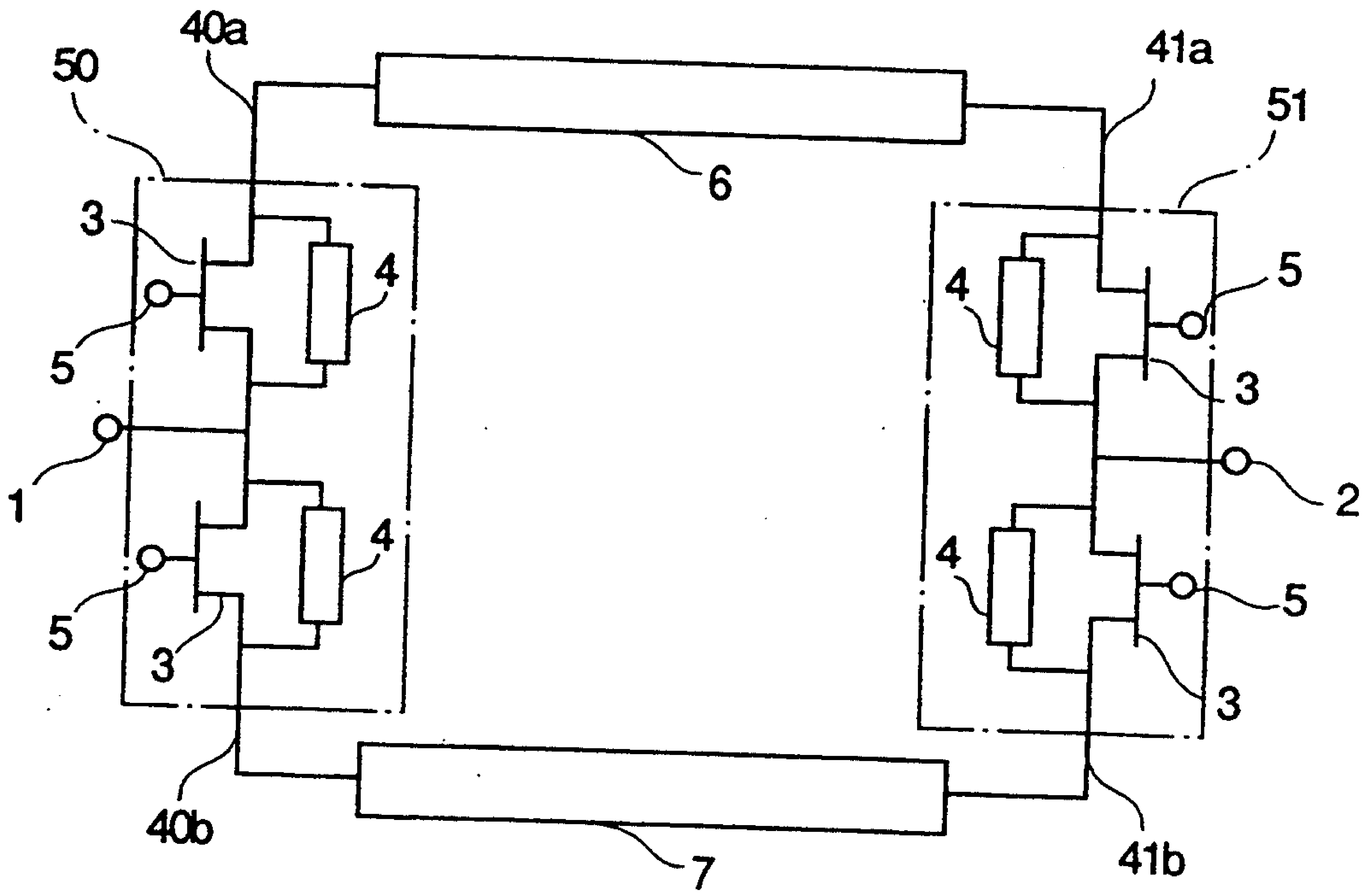


Fig.9 (Prior Art)

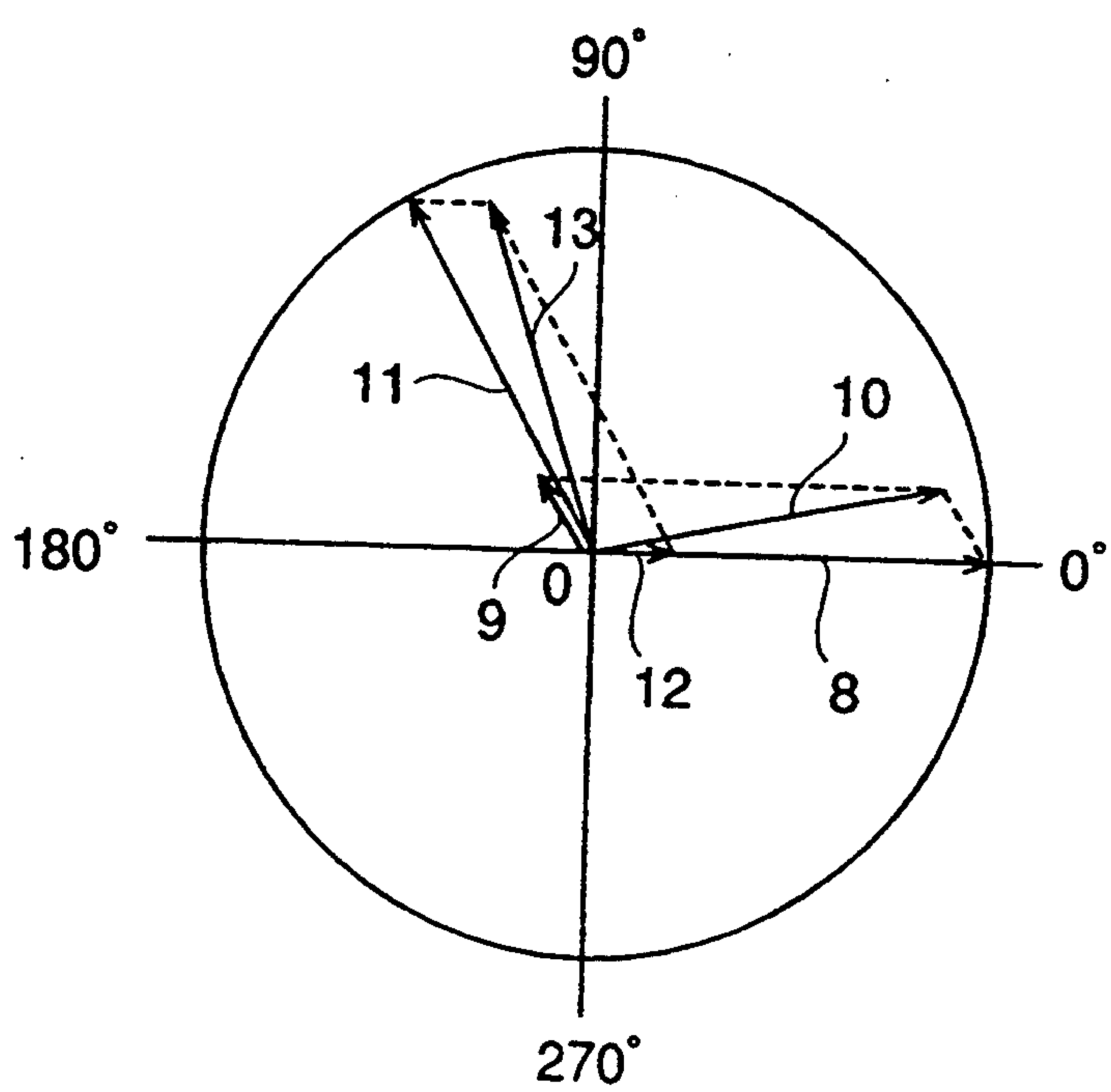


Fig.10

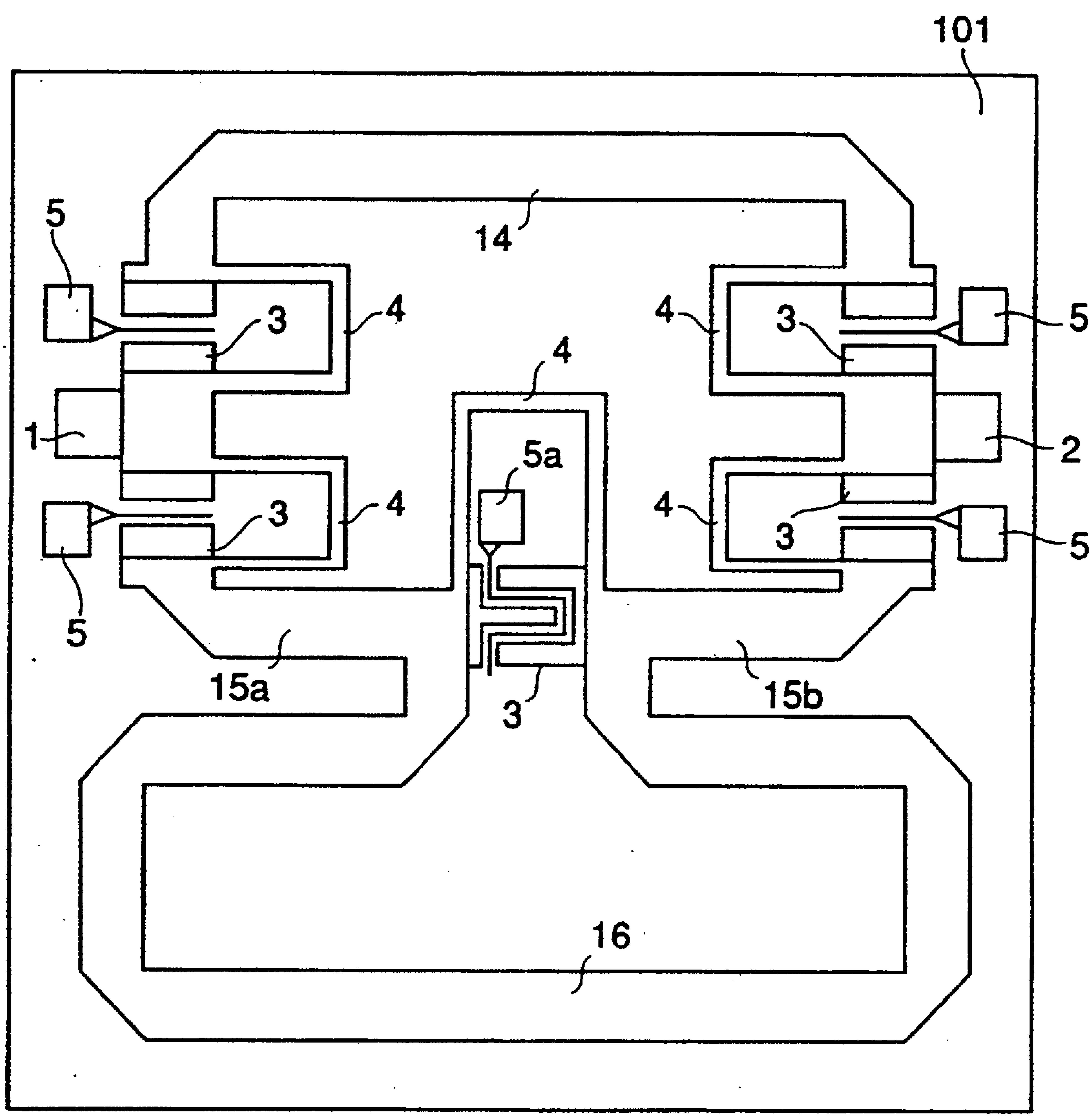


Fig.11

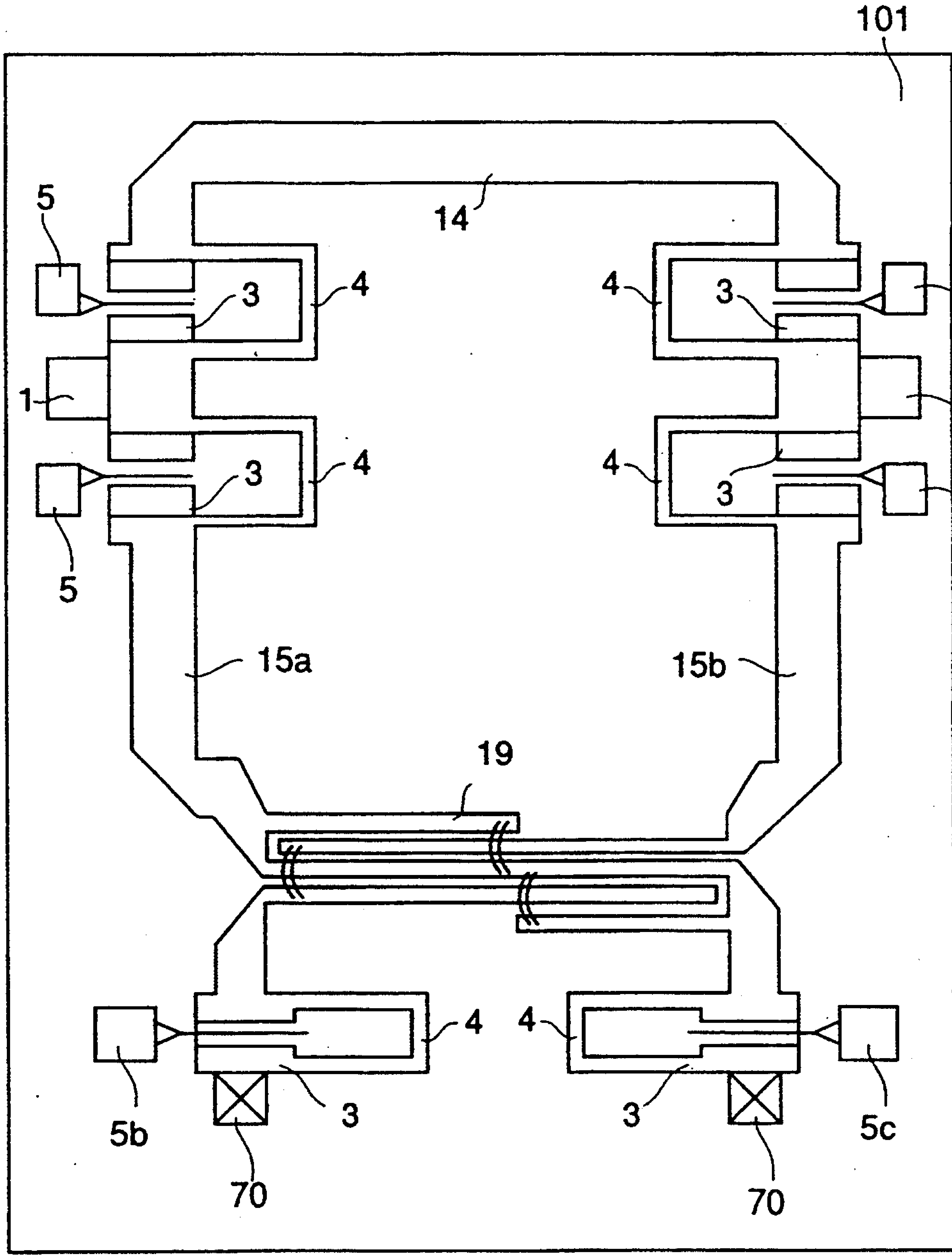


Fig.12

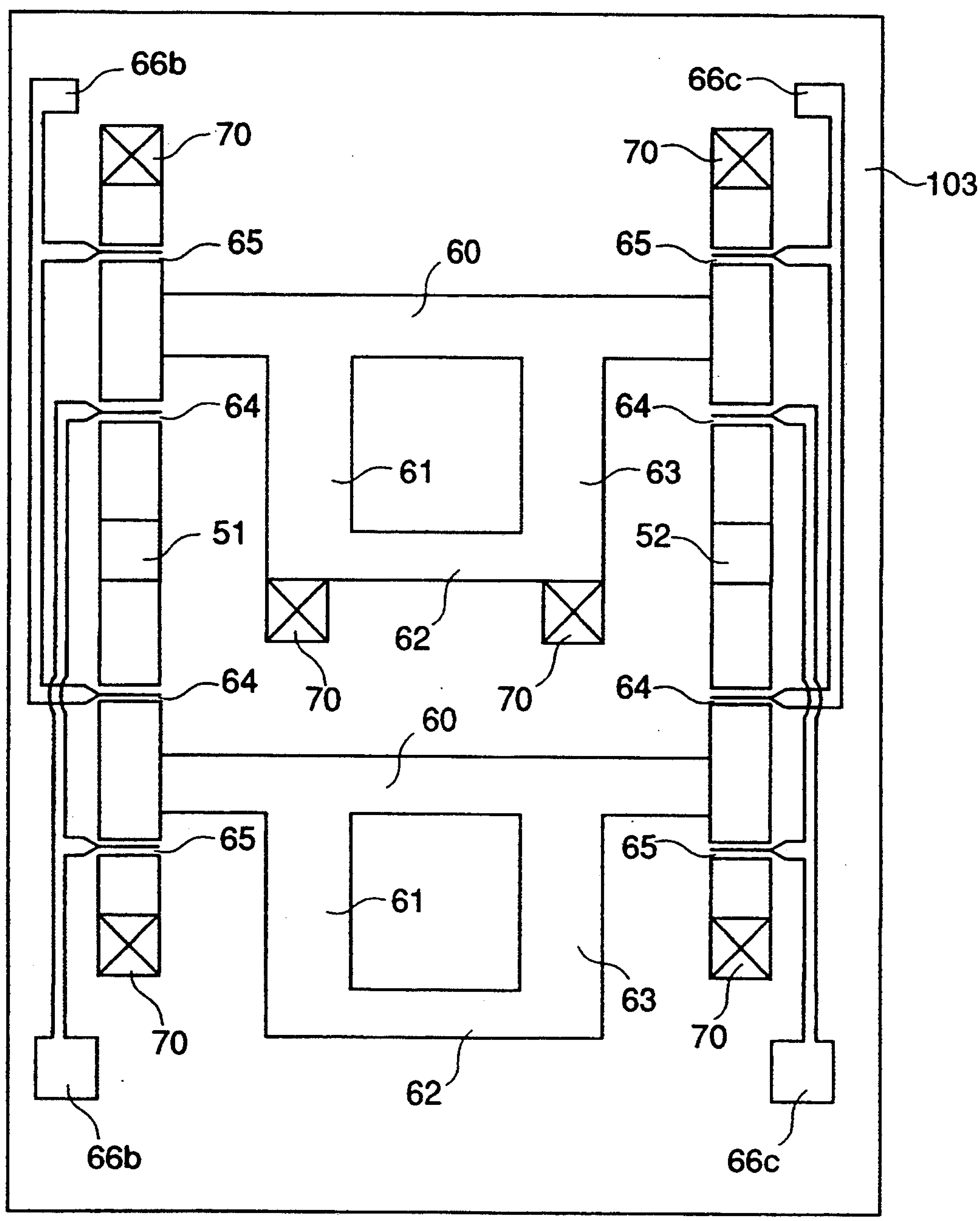
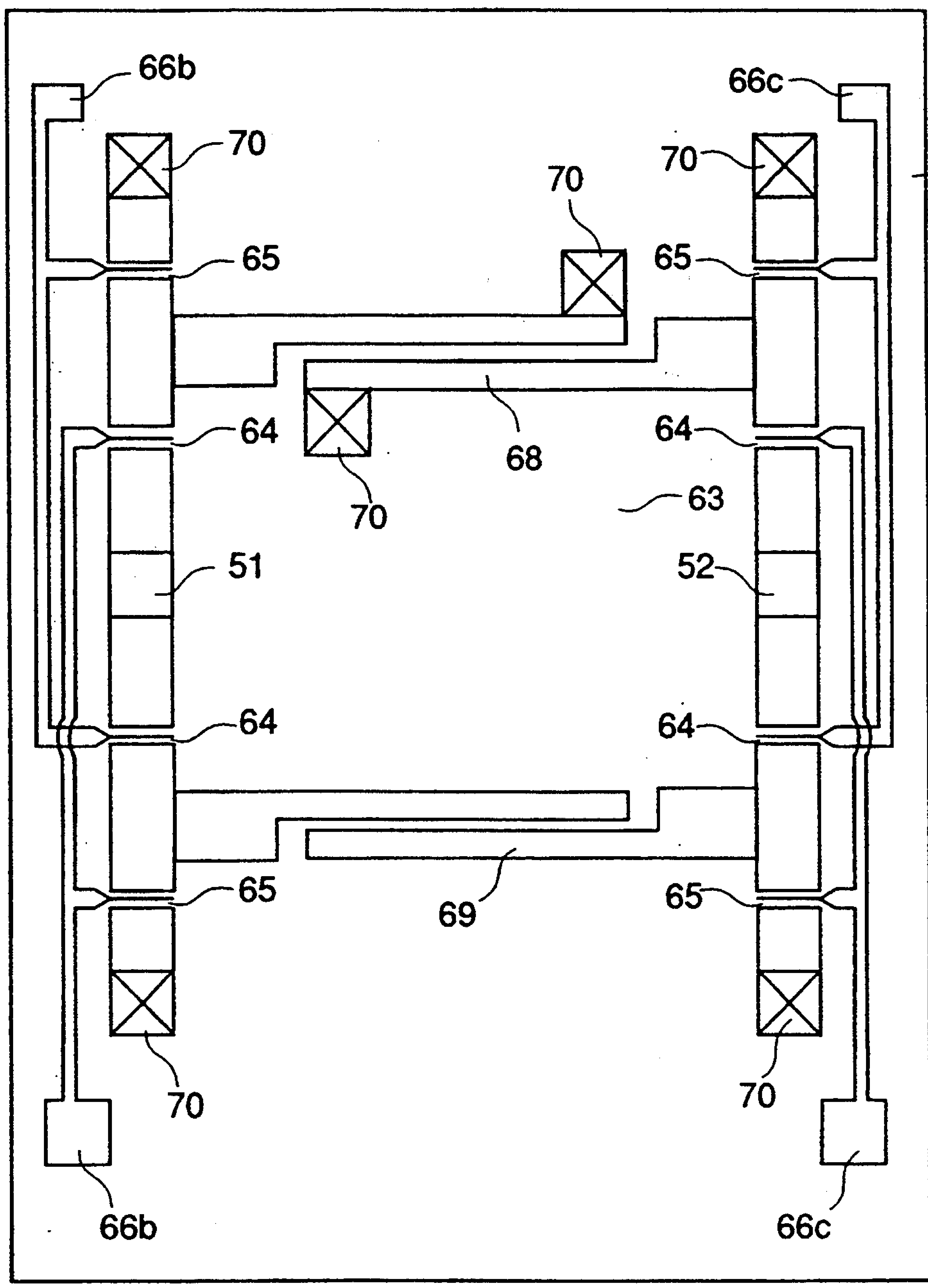


Fig.13



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70
66b
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90 DEGREE PHASE SHIFTER

FIELD OF THE INVENTION

The present invention relates to a 90° phase shifter and, more particularly, to a switched line type phase shifter.

BACKGROUND OF THE INVENTION

FIG. **8** is a circuit diagram of a conventional switched line type phase shifter. In the figure, reference numeral **1** designates an input terminal and reference numeral **2** designates an output terminal. Four field effect transistors **3** are provided at two paths from the input terminal **1** or at the two paths to the output terminal **2** (hereinafter referred to as "FET"). Reference numeral **4** designates resonance lines connected between source and drain electrodes of the FETs **3**, respectively, as resonance inductances, respectively. Reference numeral **5** designates gate bias terminals of respective FETs **3**. A reference line **6** having a predetermined electrical length α is provided between the other end of one of the input side FETs **3** and the other end of one of the output side FETs **3**. A phase difference producing line **7** having an electrical length $(\alpha+\beta)$ which is longer than that of the reference line **6** by a desired electrical length β is provided between the other end of the other one of the input side FETs **3** and the other end of the other one of the output side FETs **3**.

Description is given of the operation.

This switched line type phase shifter includes by two single pole double throw switches **50** and **51** which receive signals at the input terminals **1** and **2** and output signals to either of the two output terminals **40***a* and **40***b*, **41***a* and **41***b*, and two transmission lines **6** and **7** connected between respective output terminals of the one or the other of the two switches, that have electrical length α, $(\alpha+\beta)$, respectively. Therefore, by switching the path for the input signal which is input to the input terminal **1** of this phase shifter between that transmitted on the reference line **6** having an electrical length α to reach the output terminal **2** of this phase shifter, or that transmitted on the transmission line **7** having an electrical length $(\alpha+\beta)$ which is longer by a desired electrical length β than the reference line **6**, a phase difference β in the electrical length is obtained.

In other words, the switched line type phase shifter shown in FIG. **8** performs a switching operation of the resonance circuit comprising the FETs **3** and the resonance lines **4**. When the gate bias voltage of the FETs **3** is set at zero volts, the path between the source and drain electrodes is equivalent to a low resistance of below several Ω, meaning an on-state. When the gate bias voltage of the FET **3** is set below the pinch-off voltage, the path between the source and drain electrodes is equivalent to a parallel circuit comprising a resistance of several kΩ and a capacitance at off-state (C_T), and having a resonance determined by the off-state capacitance (C_T) and the resonance line **4** connected between the source and the drain of the FET, i.e., an off-state. Even in this off-state, however, it is actually impossible to realize an ideal off-state. Accordingly, a leakage signal is transmitted through the line of the off-state side, and as a result, a signal which is output to the output terminal of the phase shifter is the vector synthesis of the signal transmitted in the on-state line and the leakage signal transmitted in the off-state line. FIG. **9** shows a diagram of this vector synthesization.

In FIG. **9**, reference numeral **8** represents a signal vector of a signal transmitted on the reference signal **6**. Reference numeral **9** represents a signal vector of a leakage signal transmitted on the line **7**. Reference numeral **10** designates a vector obtained by synthesizing the vectors **8** and **9**. Reference numeral **11** represents a signal vector of a signal transmitted on the reference line **6**. Reference numeral **12** represents a signal vector of a signal transmitted on the line **7**. Reference numeral **13** designates a vector obtained by synthesizing the both vectors **8** and **9**. In this example, the vector **9** is in an advanced phase relative to the vector **8**, the vector **12** is in a retarded phase relative to the vector **11**, and the synthesized vector **13** is in an advanced phase by about 90° relative to the synthesized vector **10**, presenting this phase difference as the phase shift of this phase shifter.

In this way, in this microwave phase shifter, while the vector **9** is in an advanced phase relative to the vector **8**, the vector **12** is in a retarded phase relative to the vector **11**, and the electrical length β by which the electrical length $(\alpha+\beta)$ of the line **7** is longer than the line **6** is set to a value larger than 90° so that the synthesized vector **13** is at 90° in reverse phase relative to the synthesized vector **10**.

In the switched line type phase shifter of such a construction, the amplitudes of the vectors **9** and **12** vary dependent on the variation in the amplitude of the leakage signal of the FET in the off-state and the amplitudes of the vectors **10** and **13** also vary, thereby deviating the angle produced by the synthesized vectors from 90°. Therefore, it is necessary to know the amplitude of the leakage signal in the off-state FET before designing the phase shifter, and it is necessary to adjust the phase shifting by that amount. In this phase shifter, however, when the two FETs located adjacent to each other have the same leakage and the values are not coincident with the design values, the phase shift amount cannot be made 90°, and when the off-capacitances FET (C_T) vary between adjacent FETs depending on the non-uniformity of the production process, the amplitude of the leakage signal also varies, thereby varying the phase shift quantity from 90°.

The prior art switched line type phase shifter is constituted as described above, and when the off-time capacitance varies dependent on variations in processing, the quantity of signal leaking on the off-side line varies, whereby the synthesized vectors **10** and **13** shown in FIG. **9** vary, resulting in a deviation in the phase shift amount.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a switched line type 90° phase shifter that requires no consideration of by leakages through a resonance circuit.

It is another object of the present invention to provide a 90° phase shifter that can prevent phase shift variations by canceling variations in leakages through a resonance circuit.

Other objects and advantages of the present invention will become apparent from the detailed description given hereinafter; it should be understood, however, that the detailed description and specific embodiment are given by way of illustration only, since various changes and modifications within the scope of the invention will become apparent to those skilled in the art from the detailed description.

According to a first aspect of the present invention, a switched line type 90° phase shifter includes two single pole double throw switches which receive an input signal input to an input terminal and output the signal to either of two output terminals, or receive two signals respectively input to the two output terminals and output either of the two input signals to the input terminal, a reference transmission line having an electrical length α at the usage frequency, connected between terminals of the first and second single pole double throw switches, a phase difference producing transmission line having an electrical length of $(90°+\alpha)$ at the usage frequency being connected between two terminals of the first and the second single pole double throw switches, a phase inverting circuit provided switchably between a state of being inserted serially between two parts of the reference transmission line, which two parts produce the entirety of the reference transmission line, and one of the terminals of the first single pole double throw switch being an input terminal of the entire circuit, and one of the terminals of the second single pole double throw switch being an output terminal.

According to a second aspect of the present invention, a 90° phase shifter includes a phase inverting circuit comprising a resonance circuit including a switch comprising an FET and a resonance line, inserted between two parts of the reference transmission line at a position of one-half of the entire electrical length of the reference transmission line, and a half-wavelength transmission line of electrical length of 180° connected in parallel with the resonance circuit.

According to a third aspect of the present invention, the above-described phase inverting circuit is a reflector type 180° phase shifter.

According to a fourth aspect of the present invention, the above-described reflector type 180° phase shifter is a 3 dB directional coupler using a Lange coupler.

According to a fifth aspect of the present invention, the above-described reflector type 180° phase shifter is a branch line type 3 dB directional coupler.

According to the present invention, the leakage signal on a second line is in an advanced phase relative to the main signal flowing on the main line and the obtained phase shift amount surely becomes 90°. Therefore, influences on the phase shift by the leakages at the off-state of the resonance circuit are eliminated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram illustrating a circuit construction of a 90° phase shifter according to a first embodiment of the present invention.

FIG. **2** is a vector diagram illustrating an operating state of a 90° phase shifter according to the first embodiment of the present invention.

FIG. **3** is a diagram illustrating a circuit construction of a 90° phase shifter according to a second embodiment of the present invention.

FIG. **4** is a vector diagram illustrating an operating state of the 90° phase shifter according to the second embodiment of the present invention.

FIG. **5**(*a*) is a diagram illustrating an equivalent circuit of a branch line type 3 dB directional coupler used as a 180° reflector type phase shifter **20** in the 90° phase shifter according to the third embodiment of the present invention and FIG. **5**(*b*) is a diagram illustrating an equivalent circuit of the branch line type 3 dB directional coupler in a state where the load terminals **58** and **59** are grounded, FIG. **5**(*c*) is a diagram illustrating an equivalent circuit of FIG. **5**(*b*), FIG. **5**(*d*) is a diagram illustrating an equivalent circuit of the branch line type 3 dB directional coupler in a state where the load terminals **58** and **59** are opened, and FIG. **5**(*e*) is a diagram illustrating an equivalent circuit of FIG. **5**(*d*).

FIG. **6** is a diagram illustrating an equivalent circuit of the 180° reflector type phase shifter of a branch line 3 dB directional coupler in a 90° phase shifter according to the third embodiment of the present invention.

FIG. **7** is a diagram illustrating an equivalent circuit of a 180° reflector type phase shifter using a 3 dB directional coupler employing a Lange coupler in a 90° phase shifter according to a fourth embodiment of the present invention.

FIG. **8** is a diagram illustrating a circuit construction of a prior art 90° phase shifter.

FIG. **9** is a vector diagram illustrating an operating state of the prior art 90° phase shifter.

FIG. **10** is a diagram illustrating a circuit pattern of a 90° phase shifter according to a first embodiment of the present invention.

FIG. **11** is a diagram illustrating a circuit pattern of a 90° phase shifter according to a second embodiment of the present invention.

FIG. **12** is a diagram illustrating a circuit pattern of a 180° reflector type phase shifter using a branch line type 3 dB directional coupler of a 90° phase shifter according to a third embodiment of the present invention.

FIG. **13** is a diagram illustrating a circuit pattern of a 180° reflector type phase shifter using a Lange coupler of a 90° phase shifter according to a fourth embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

EMBODIMENT 1

FIG. **1** is a diagram illustrating a 90° phase shifter according to a first embodiment of the present invention. In the figure, the same reference numerals as those shown in FIG. **8** designate the same or corresponding elements. Reference numeral **14** designates a 90° phase shifting transmission line having an electrical length of $(\alpha+90°)$ as a sum of the electrical length α of the reference line and the electrical length 90° at the use frequency. Reference numerals **15***a* and **15***b* designate one half reference lines each having an electrical length of $\alpha/2$ which is equal to one half of the electrical length α of the reference line described in the 90° phase shift line **14**. Together lines **15***a* and **15***b* are a reference transmission line **15** of electrical length α. As in FIG. **8**, reference numerals **3** and **4** respectively designate FET switches and a resonance inductance lines which are provided between the two one half reference lines **15***a* and **15***b* and connected in parallel with each other as a parallel resonance circuit. A transmission line **16** of an electrical length of 180° as a phase inverting circuit, is provided in parallel with the parallel resonance circuit comprising the FET switches **3** and the resonance lines **4**.

FIG. **10** shows a layout diagram of the 90° phase shifter of this first embodiment. In FIG. **10**, the same reference numerals are used to represent those described above and the circuit patterns of this 90° phase shifter are produced on a substrate **101**.

The fundamental operation of the 90° phase shifter of this first embodiment is approximately the same as that of the prior art phase shifter, although the signal leaked from the off-state FET in the prior art switched line type phase shifter is inverted in its phase by the phase inverting circuit **16**.

FIG. **2** shows a vector diagram illustrating an operation state of this 90° phase shifter. A description is given of the operation with reference to this FIG. **2**.

First of all, the side of the reference lines **15***a* and **15***b* where the phase inverting circuit **16** is connected is turned on, so the phase inverting circuit **16** is short circuited, i.e., turned off, thereby the phase shifter is in a state not inverting the phase, while the side of the line **14** for shifting the signal by 90° is turned off i.e., disconnected. Then, the signal passing through the reference line **15** is represented by the signal vector **8** in FIG. **2**, and the leakage signal passing through the 90° phase shifting line **14** is represented by the signal vector **9**. Therefore, the output signal represented by the signal vector **10** obtained by the vector synthesization of the vectors **8** and **9** is output.

Thereafter, the FET switch **3** at the reference line **15** provided with the phase inverting circuit **16** is turned off, so the phase inverting circuit **16** is effective, whereby the phase shifter enters a phase inverting state, when the 90° phase shifting line **14** is turned on, i.e., connected. Then, the signal passing on the line **14** is represented by the signal vector **13**, and the signal passing on the line **15** and the phase inverting circuit **16** is represented by the signal vector **17**. Therefore, the output signal represented by the signal vector **18** obtained by the vector synthesization of the vectors **13** and **17** is output.

By performing such an operation, the signal leaking on the off side line becomes 90° phase advanced signals **9** and **17** relative to the on side line signals **8** and **13** in both cases, and because the difference in the electrical length between the lines **14** and **15** is set to an electrical length generating a phase difference of 90°, the vector **10** and the vector **18** always realize a phase difference of 90° therebetween. In addition, if the characteristics of the FETs **3** which are produced adjacent each other are the same, even when the off-capacitance C_T of the FET varies depending on the non-uniformity of processing, the vectors **9** and **17** vary by the same amount at the same time, and the phase difference between the vector **10** and the vector **18** is always kept at 90°, thereby providing a 90° phase shifter with stable operation.

The 90° phase shifter of this first embodiment includes a switched line type 90° phase shifter such that a phase inverting circuit **16** is switched between a state where the phase inverting circuit is inserted in series between two parts of the reference line and a state where it is not inserted, that is added to a construction where the difference in the electrical length between the reference lines **15***a* and **15***b* and the phase difference producing line **14** is 90°, and thereby the leakage signal flowing on the reference line or the phase difference producing line when the resonance circuit is in off-state reliably has an advanced phase by 90° relative to the signal of the on side line. Accordingly, the influence on the phase shift amount due to the leakage signal becomes the same in both cases where the leakage signals are generated in any of the two lines, and the phase shifter cancels the influences of this leakage signal in its operation. Therefore, so far as the leakage signal of the FETs adjacent each other are the same, it is neither required to know the amplitude of the leakage signal nor to consider the same before designing the phase shifter, thereby simplifying circuit design as well as improving the precision of the circuit design to a great extent. Furthermore, non-uniformities due to processing can be tolerated, thereby accomplishing a high yield.

EMBODIMENT 2

FIG. **3** is a diagram illustrating a 90° phase shifter according to a second embodiment of the present invention.

In the first embodiment the phase inverting circuit is a 180° line **16** connected in parallel with the resonance circuit comprising the FETs **3** and the resonance lines **4**, but in this second embodiment the phase inverting circuit is a 180° reflector type phase shifter **20**.

FIG. **11** shows a pattern layout of this second embodiment. In FIG. **11**, reference numeral **19** designates a 3 dB directional coupler using a Lange coupler, a 180° reflector type phase shifter **20** with two switches each comprising an FET **3** and a resonance line **4**.

Reference numeral **70** designates a ground pad and reference numeral **102** designates a substrate.

FIG. **4** is a vector diagram showing an operation state of the 90° phase shifter of this second embodiment, and a description is given of the operation of 90° phase shifter of this second embodiment with reference to FIG. **4**.

First of all, the reference line **15** comprising reference line parts **15***a* and **15***b* provided with the 180° reflector type phase shifter **19** is turned on, the reflector type phase shifter **19** is turned off, i.e., it is set to a state where the phase inversion is not performed, and the 90° phase shifting line **14** is turned off i.e., disconnected. Then, the signal on line **15** is represented by the signal vector **8**, and the signal on the line **14** is represented by the signal vector **9**. Therefore, the output signal represented by the signal vector **10** obtained by the synthesization of the vectors **8** and **9** is output.

Next, the line **15** provided with the reflector type phase shifter **19** is turned off, the reflector type phase shifter **19** is turned on, i.e., it is set to a state where the phase inversion is performed, and the 90° phase shifting line **14** is turned on i.e., connected. Then, the signal on line **14** is represented by the signal vector **13** and the signal on the line **15** is represented by the signal vector **17**. Therefore, the output signal represented by the signal vector **18** obtained by the synthesization of the vectors **13** and **17** is obtained.

By performing such an operation, the leaked signal on the off side line is in an advanced phase by 90° in all cases relative to the signal of the on side line, and further, since the lines **14** and **15** are produced having electrical lengths generating a phase difference of 90°, the vector **10** and the vector **18** always have a phase difference of 90°. In addition, even when the off-capacitance C_T, of the FET is changed because of non-uniformities in the production process, if the FETs **3** adjacent each other have the same characteristics, the vectors **9** and **17** vary by the same amount at the same time, and the phase difference between the vector **10** and the vector **18** which are to be synthesized is always kept at 90°, thereby providing a 90° phase shifter with stable operation.

EMBODIMENT 3

A third embodiment of the present invention includes a 3 dB directional coupler functioning as the 180° reflector type phase shifter **20** in the above described second embodiment.

(1) Description of a branch line type 3 dB directional coupler:

FIG. **5**(*a*) shows an equivalent circuit of a branch line type 3 dB directional coupler. The transmission lines **60** to **63** shown in FIGS. **5**(*a*)–**5**(*e*) all have an electrical length of 90°. Further, the characteristic impedance of the transmission lines **60** and **62** are Z_0, and those of the transmission lines **61** and **63** are $Z_0/2$. In addition, reference numeral **51** designates an input terminal, reference numeral **52** designates an output terminal, and reference numerals **58** and **59** designate load terminals.

FIG. **5**(*b*) shows an equivalent circuit of a branch line type 3 dB directional coupler in which load terminals **58** and **59** are grounded. Since the load terminals **58** and **59** are grounded, it is thought to be equivalent to a circuit where the transmission line **62** is absent. Since the electrical lengths of respective transmission lines are 90°, the load terminal **58** is grounded for the transmission line **61**, and the impedance viewed from the input terminal **51** toward the transmission line **61** is infinite. Similarly, for the transmission line **63**, the impedance viewed from the output terminal **52** is infinite. Accordingly, the equivalent circuit of FIG. **5**(*b*) is represented by an equivalent circuit of FIG. **5**(*c*).

FIG. **5**(*d*) shows an equivalent circuit of a branch line type 3 dB directional coupler in which load terminals **58** and **59** are open. Since the load terminals **58** and **59** are open, the impedance viewed from the input terminal **51** toward the transmission line **61** is zero, i.e., meaning a short-circuited state. Similarly, the impedance viewed from the output terminal **52** toward the transmission line **63** is zero. On the contrary, for the transmission line **60**, the impedances viewed from the input terminal **51** and the output terminal **52** are both infinite, and it is thought to be equivalent to a circuit where the transmission line **60** is absent. Accordingly, the equivalent circuit of FIG. **5**(*d*) is represented by an equivalent circuit of FIG. **5**(*e*).

Since the electrical lengths of respective transmission circuits are 90°, the difference in the electrical lengths in the equivalent circuits of FIG. **5**(*c*) and FIG. **5**(*e*) are 180°, thereby constituting a reflector type phase shifter **20** of FIG. **3**.

(2) Description of a reflector type phase shifter **20** in the 90° phase shifter of the third embodiment:

FIG. **6** shows an equivalent circuit of the reflector type phase shifter employing a branch line 3 dB directional coupler **19**. In FIG. **6**, reference numeral **64** designates FETs which are connected in series in the signal transmission path between the signal input terminal **51** and the signal output terminal **52**. FETs **65** are connected in parallel with the signal transmission path, i.e., with FETs **64**. Reference numerals **66***b* and **66***c* designate gate bias terminals of the FETs **64** and **65**. An SPDT switch **67** with wide band characteristics is constituted by these FETs **64** and **65**. The terminal **51** of FIG. **6** is employed as the input terminal A of the 3 dB directional coupler **19** of FIG. **3**, the terminal **52** of FIG. **6** as the output terminal C of FIG. **3**, the terminal **66***b* of FIG. **6** as the terminal **5***b* of FIG. **3**, and the terminal **66***c* of FIG. **6** as the terminal **5***c* of FIG. **3**.

FIG. **12** shows a pattern layout of the reflector type phase shifter of FIG. **6** as the third embodiment of the present invention. In FIG. **12**, reference numerals are used to designate elements the same as or corresponding to those described above. Reference numeral **70** designates a ground pad and reference numeral **103** designates a substrate.

(3) Description of operation of a 90° phase shifter of this third embodiment:

The 90° phase shifter of this third embodiment has a bandwidth that is the same as that of the branch line type directional coupler as ±10% from the center frequency, where the center frequency is 300 MH_2 to 30 GH_z.

The 90° phase shifter of this embodiment employing a reflector type 180° phase shifter performs fundamentally the same operation as that of the 90° phase shifter of the first embodiment.

A vector diagram showing the operation of the 90° phase shifter of this third embodiment is the same as that of FIG. **4**.

(4) Description of effects of the 90° phase shifter of the third embodiment:

By carrying out such an operation, the signal that leaks on the off side line becomes the signal in an advanced phase by 90° relative to the signal on the on side line in all cases, and further because the transmission lines **14** and **15** have electrical lengths producing a phase difference of 90°, the vector **10** and the vector **18** always have a phase difference of 90°. In addition, even if the off-capacitance (C_T) of the FET varies depending on the non-uniformity of production processing, if the characteristics of the FETs **3** which are located adjacent each other are the same, then the vectors **9** and **17** vary by the same amount at the same time, and the phase difference between the vector **10** and the vector **18** which are to be synthesized with each other is always kept at 90°, thereby providing a 90° phase shifter having stable operation.

EMBODIMENT 4

A 180° phase shifter that performs the same operation as that which is performed by using the above described branch line type 3 dB directional coupler can be realized by using a Lange coupler. A 90° phase shifter of this fourth embodiment of the present invention includes the 180° reflector type phase shifter **20** in the third embodiment, the equivalent circuit of which is shown in FIG. **7**.

In FIG. **7**, reference numeral **68** designates a Lange coupler which has its load terminals grounded. Reference numeral **69** designates a Lange coupler which has its load terminals open. Reference numerals **64** to **67**, **51** and **52** are the same as those shown in FIG. **6**. That is, reference numeral **64** designates FETs which are connected in series with the signal transmission path between the input terminal **51** and the output terminal **52**. Reference numeral **65** designates FETs which are connected in parallel with the signal transmission path, i.e., the FETs **64**. Reference numeral **66** designates a gate bias terminal of the FETs **64** and **65**. Reference numeral **67** designates an SPDT switch having a wide band characteristics including these FETs **64** and **65**. The 90° phase shifter of this embodiment using a reflector type 180° phase shifter employs the terminal **51** of FIG. **7** as the input terminal A of the 3 dB directional coupler **19** of FIG. **3**, the terminal **52** of FIG. **7** as the output terminal C of FIG. **3**, the terminal **66***b* of FIG. **7** as the terminal **5b** of FIG. **3**, and the terminal **66c** of FIG. **7** as the terminal **5c** of FIG. **3**.

FIG. **13** shows a circuit pattern layout of a 180° reflector type phase shifter of this fourth embodiment. In the figure, the same reference numerals are used to designate elements the same as or corresponding to the those described above, and reference numeral **104** designates a substrate.

The 90° phase shifter of this fourth embodiment using the reflector type 180° phase shifter of FIG. **7**, for which circuit pattern is shown in FIG. **13**, performs the same way as that of the 90° phase shifter of the above described second and third embodiments. Here, the 180° reflector type phase shifter of FIG. **7** has a wide band characteristic which is operable for ±50% of the center frequency because the band of the Lange coupler amounts to about ±50% of the center frequency, where the center frequency is 300 MH_z to 30 GH_z.

As is evident from the foregoing description, according to the present invention, a switched line type 90° phase shifter has as the difference in electrical lengths between a reference line and a phase difference producing line of 90° and a phase inverting circuit is added to the reference line switchable between a state where it is connected in series between two parts of the reference line and a state where it is not connected the two parts of the reference line. Leakage signals flowing on the reference line and on the phase difference producing line when the resonance circuit is in an off-state are reliably in a 90° advanced phase relative to the signal on the on side line, whereby the phase shift due to the leakage signal is the same as in cases where the leakage signal is generated in either of the lines, whereby the influences by the leakage signals are canceled in the operation of the phase shifter. Therefore, since the leakage signal of the FET located adjacent each other are the same, there is no necessity to know in advanced the amplitude of the leakage signal or to consider the magnitude of the leakage signal in advance of designing the phase shifter, and the circuit design can be performed quite easily and with high precision. Further, nonuniformities depending on the production processes can be tolerated and a high yield can be achieved.

What is claimed is:

1. A 90° phase shifter comprising:

first and second single pole double throw (SPDT) switches, the first SPDT switch receiving an input signal input to an input terminal of said first SPDT switch and outputting the signal to one of first and second output terminals of said first SPDT switch, and the second SPDT switch receiving the signals from said first SPDT switch at one of first and second input terminals of said second SPDT switch and outputting the signal at an output terminal of said second SPDT switch;

a reference transmission line having an electrical length of α connected between said first output terminal and said first input terminal of said first and second SPDT switches, respectively, said reference transmission line being divided into two parts of substantially equal electrical lengths of $\alpha/2$;

a phase difference producing transmission line having an electrical length of $(90°+\alpha)$ at a usage frequency connected between said second output terminal and said second input terminal of said first and said second SPDT switches, respectively; and

a phase inverting circuit connected to and between the two parts of said reference transmission line and including a phase shift selection switch for switching said phase inverting circuit between connection to the two parts of said reference transmission line and disconnection from the two parts of said reference transmission line, said input terminal of said first SPDT switch being an input terminal of said phase shifter and said output terminal of said second SPDT switch being an output terminal of said phase shifter.

2. The 90° phase shifter of claim **1**, wherein said phase selection switch comprises an FET and a resonant line connected in parallel and to the parts of said reference transmission line; and

said phase inverting circuit includes a half-wavelength line having an electrical length of 180° at the usage frequency connected in parallel with said phase selection switch.

3. The 90° phase shifter of claim **1**, wherein said phase inverting circuit comprises a reflector type 180° phase shifter.

4. The 90° phase shifter of claim **3**, wherein said reflector type 180° phase shifter comprises a 3 dB directional Lange coupler.

5. The 90° phase shifter of claim **3**, wherein said reflector type phase shifter comprises a 3 dB directional branch line coupler.

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